Effectively Managing Turnarounds and Shutdowns In Low Earth Orbit

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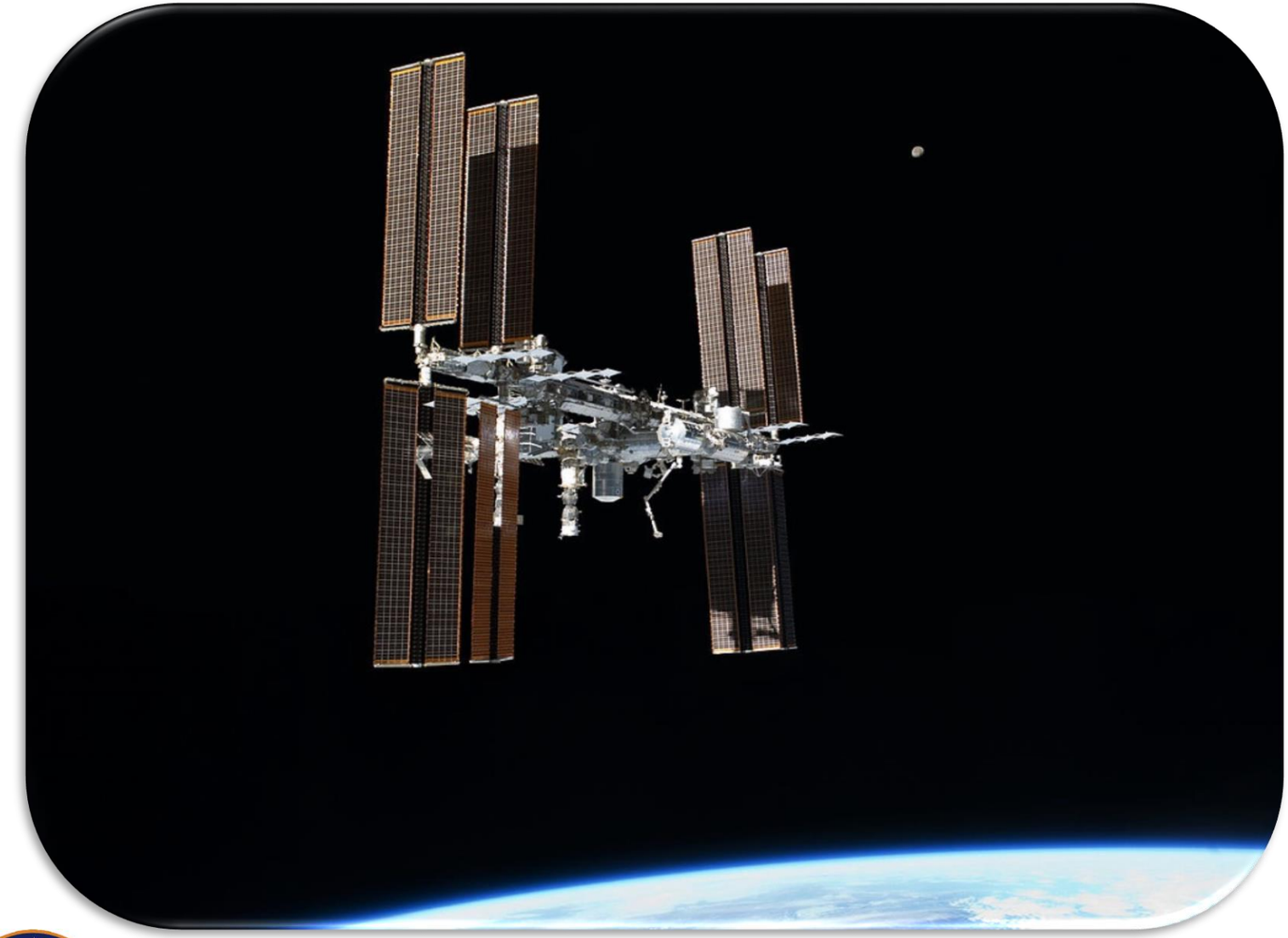
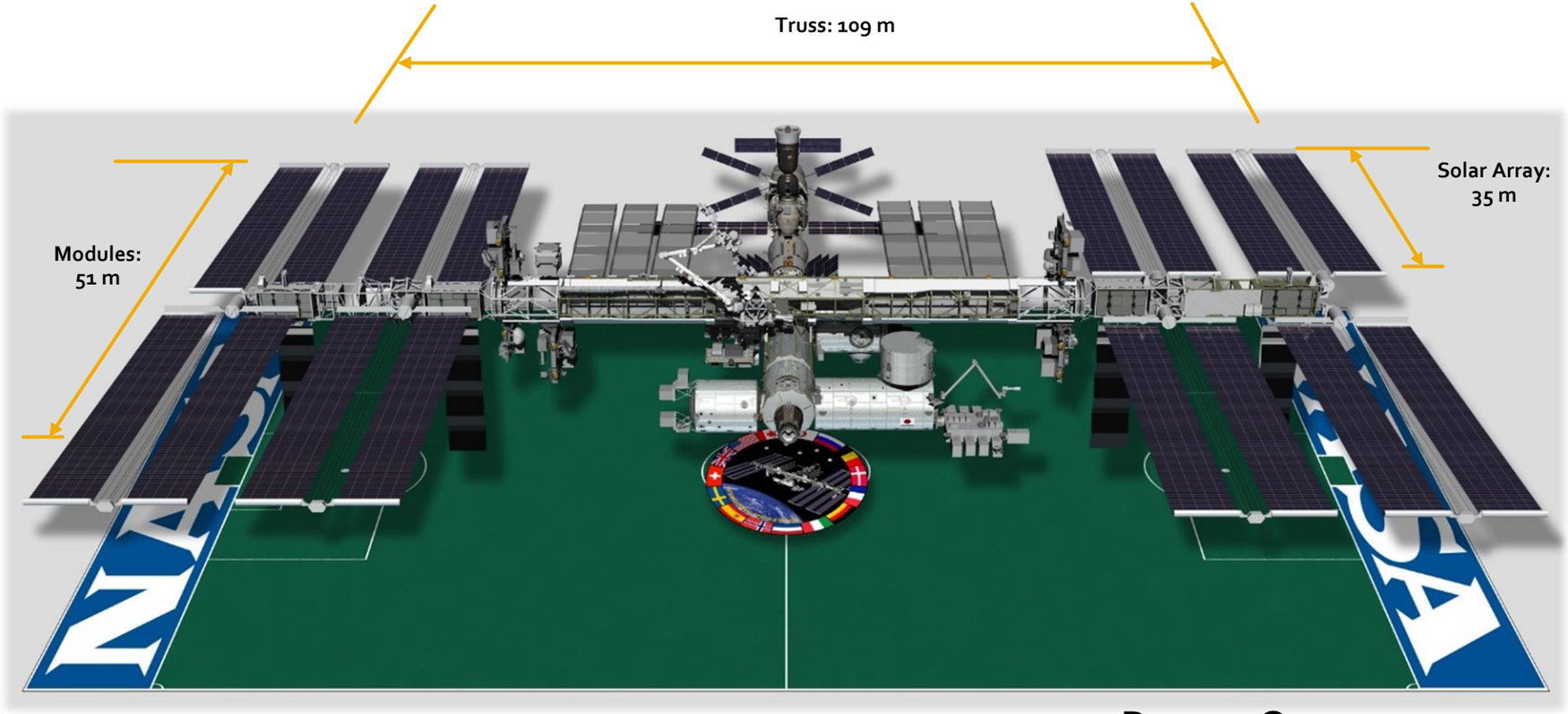


- **Microgravity research laboratory assembled in orbit between 1998-2011**
- **Occupied continuously since 2000**
- **Components built by companies across 16 nations**
- **170+ launches from Florida, Virginia, Russia, Japan, and French Guiana**
- **Research crew of 6 astronauts and cosmonauts serve 6 month stay**

Earth's Only Microgravity Research Laboratory



LARGE, CAPABLE LABORATORY:

Mass: 420,000 kg
Habitable Volume: 388 m^3
Solar Power Generation Capability: 84 kW
Numerous external and internal research platforms

REMOTE OUTPOST:

Altitude: 415 km (250 mi)
Orbital Speed: 28,000 kph (7.8 km/sec)
17,500 mph (5 mi/sec)
Orbital Period: 90 minutes
(16 sunrises/sunsets per day)

ISS Assembly

- **163 launches to ISS between Nov 1998 and Nov 2015**
  - **37 U.S. space shuttle assembly missions to ferry components, logistics, consumables, research, and crew between Earth and ISS**
- **Space Shuttle was primary vehicle used to assemble ISS**
  - **Tremendous mass-to-orbit and orbit-to-Earth capability**
  - **Carried up to 7 crewmembers**
  - **Capability for up to ~10 docked days**
  - **Had its own airlock and robotic arm**
  - **Crew training occurred up until very close to launch**
    - » **Late changes could be absorbed as the crews launched from the US**


ISS018E008788

Supportability & Logistics

- **Original plan**
  - US Orbital Segment designed to be launched and serviced by the space shuttle
  - Maintenance concept centers on the “Orbital Replacement Unit” (ORU)
  - Minimize turnaround downtime by doing depot-level maintenance on Earth and refly the hardware

- **Plans changed – shuttle retirement**
  - Launch as many repair parts, especially parts only shuttle could launch, before the program ended
  - Develop new means and methods for diagnostics and troubleshooting as well as in-situ repair
  - Next generation spare parts now being designed to use same footprint but have separate, stand-alone components that are able to be launched on today’s rockets

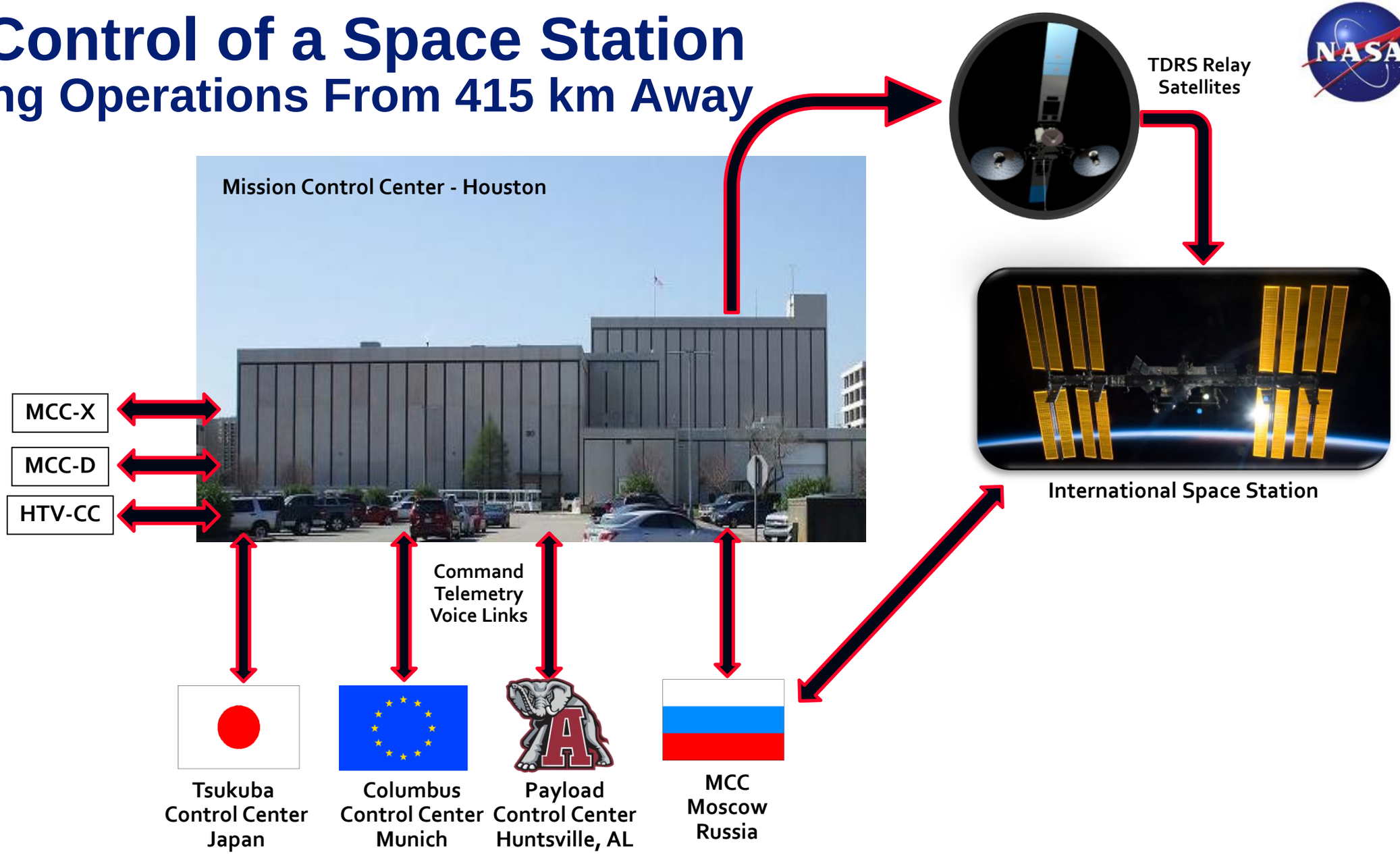
- **Lesson: Anticipate paradigm shifts if you can**
  - ISS was designed in the 1980s and 1990s when the expectation was that space shuttle would fly forever
  - Adapting now is much harder and likely much more expensive

Logistics Skip Cycles
Planning for Unexpected 'Shutdowns'

- **ISS resupply requires Earth-launched cargo missions**
- **Spaceflight is complex and HARD**
  - **Launch schedules change frequently**
  - **Mission/cargo needs change**
  - **Weather happens**
  - **Rapid Unplanned Disassembly (RUD) happens**
    - » **Orbital Sciences "Orb-3" loss after liftoff 28 Oct 2014**
      - **2,200 kg lost**
    - » **Russian Progress 59P loss at 3rd stage separation 28 Apr 2015**
      - **2,400 kg lost**
    - » **SpaceX CRS-7 loss during 1st stage 28 June 2015**
      - **1,900 kg + International Docking Adapter lost**
    - » **SpaceX AMOS-6 loss ~4 minutes prior to engine test**
      - **USD $195M satellite, rocket, lost; significant launch pad damage**

- **Plan a skip cycle so you can tolerate schedule changes or logistics losses**
  - **ISS currently uses ~4-6 month skip cycles for critical consumables**

Remote Control of a Space Station
Orchestrating Operations From 415 km Away



Mission Control Center – Houston

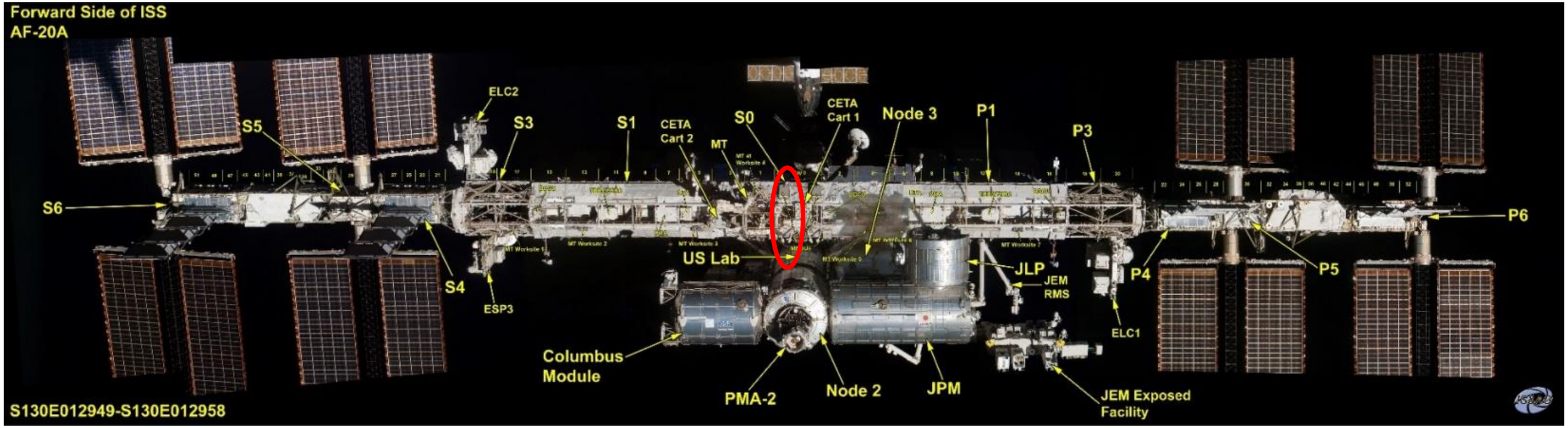
MBSU Failure – Fall 2011

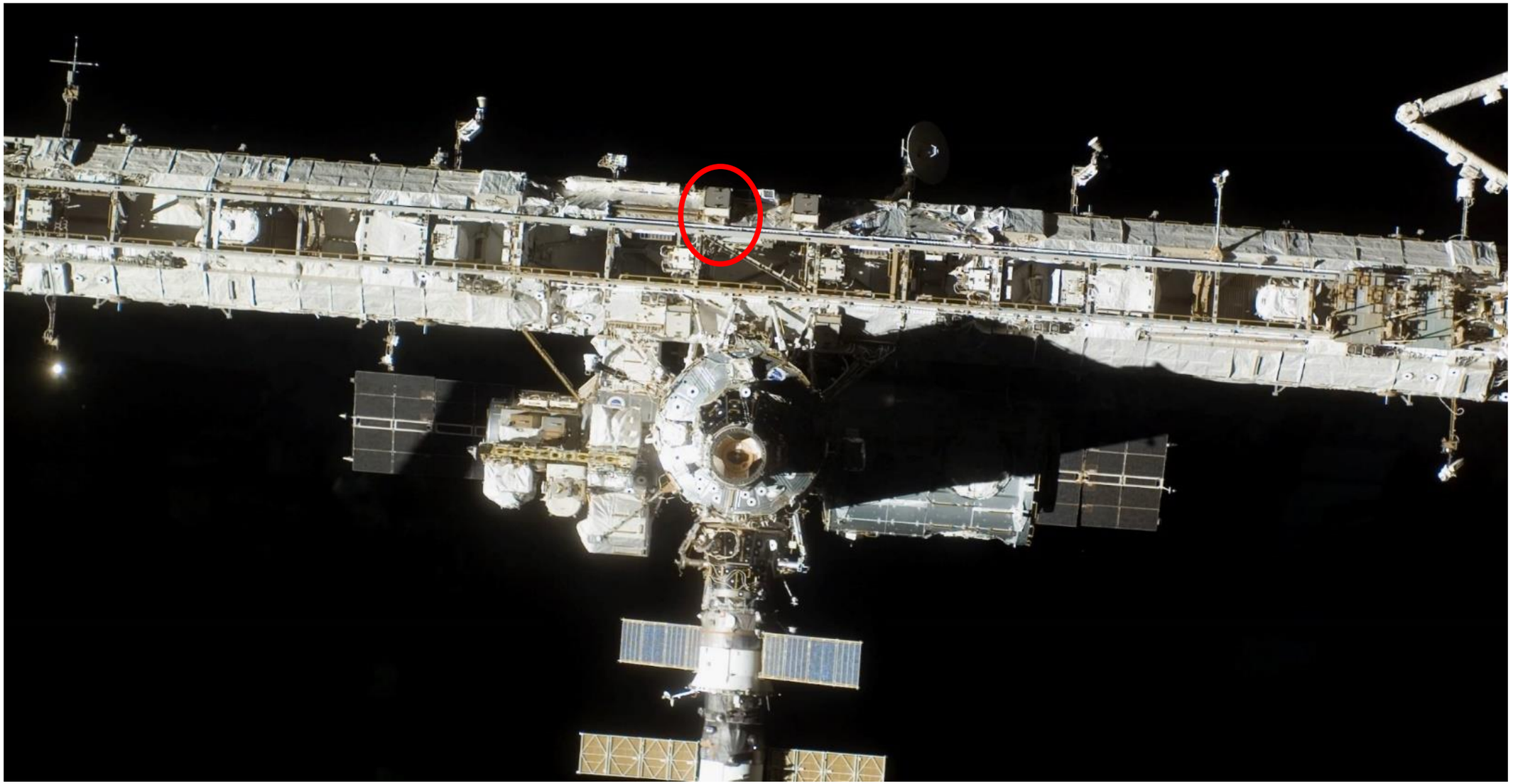
When a Choreographed Turnaround Turns into An Unplanned Shutdown

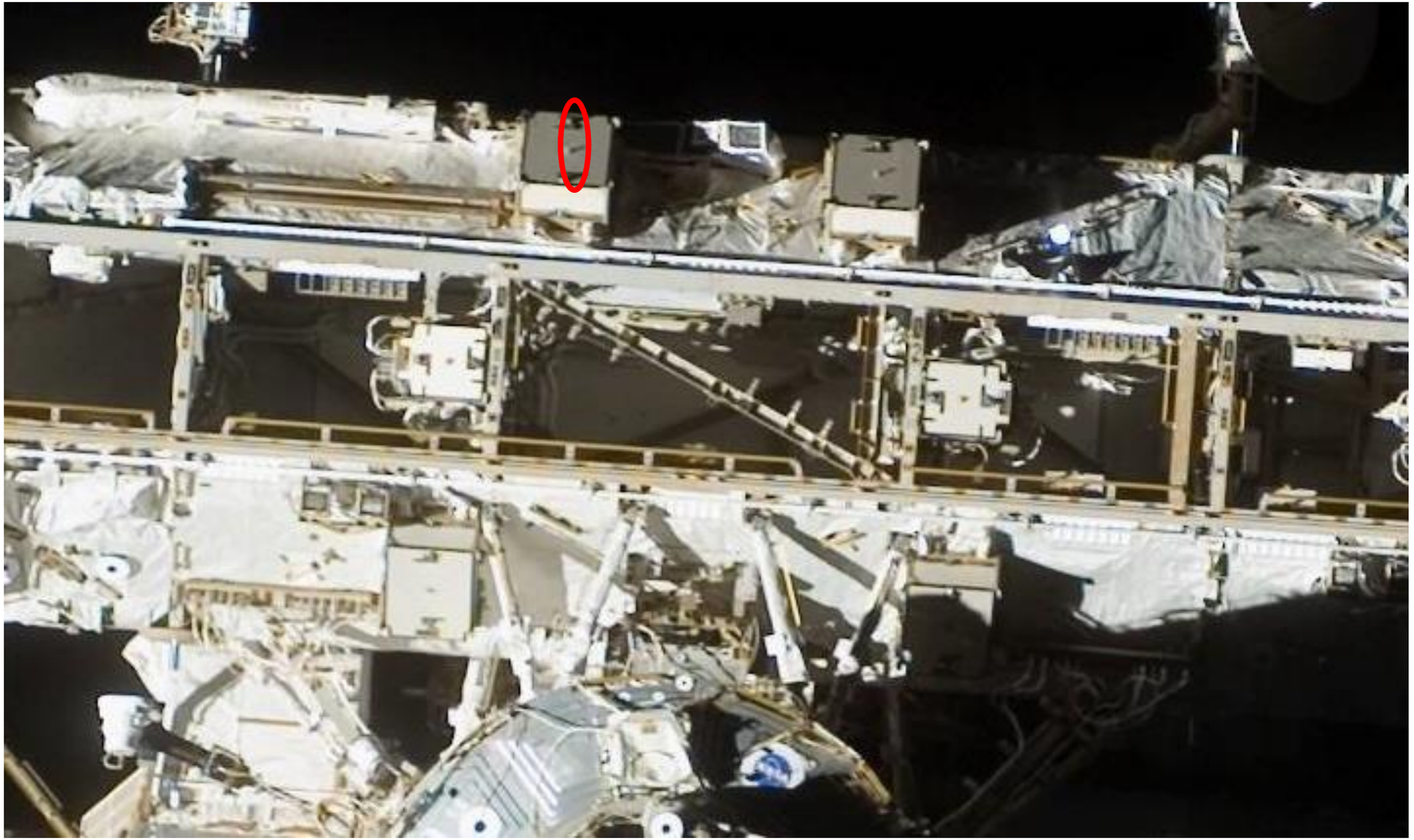
- **Main Bus Switching Unit (MBSU)**
- **Key piece of hardware that routes primary power (~160 VDC) from the 8 solar array-fed power channels to downstream load distribution equipment**
  - **4 MBSUs on ISS, each routing 2 power channels**
  - **Each can be 'cross tied' to 2 other MBSUs in times of failure so other channels can power a MBSU's loads**
  - **Computer commands direct the opening/closing of switches in each MBSU to perform power routing**
    - » **Switch states are generally not changed (can go unchanged for months at a time)**

MBSU Failure – Fall 2011

- **MBSU 1 had a circuit card failure in Fall 2011 where it stopped communicating with its controlling computer**
  - **Switches remained open/closed, power was still being passed, but switch position could not be changed**
- **Decided the current condition was acceptable in the short term but the MBSU needed to be replaced "soon"**
  - **Replacement spacewalk targeted for Fall 2012**

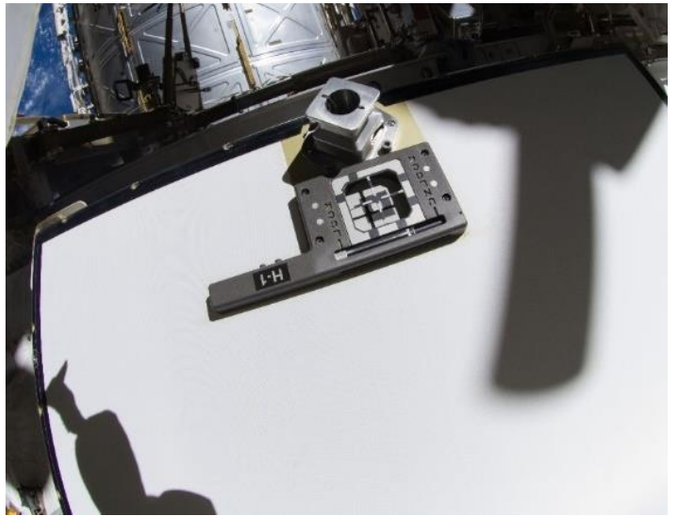

Forward Side of ISS
AF-20A
ELC2
S5
S3
S1
CETA
Cart 2
S0
MT
CETA
Cart 1
Node 3
P1
P3
S6
P6
US Lab
JLP
JEM
RMS
P4
P5
S4
ESP3
ELC1
Columbus
Module
PMA-2
Node 2
JPM
JEM Exposed
Facility
S130E012949-S130E012958



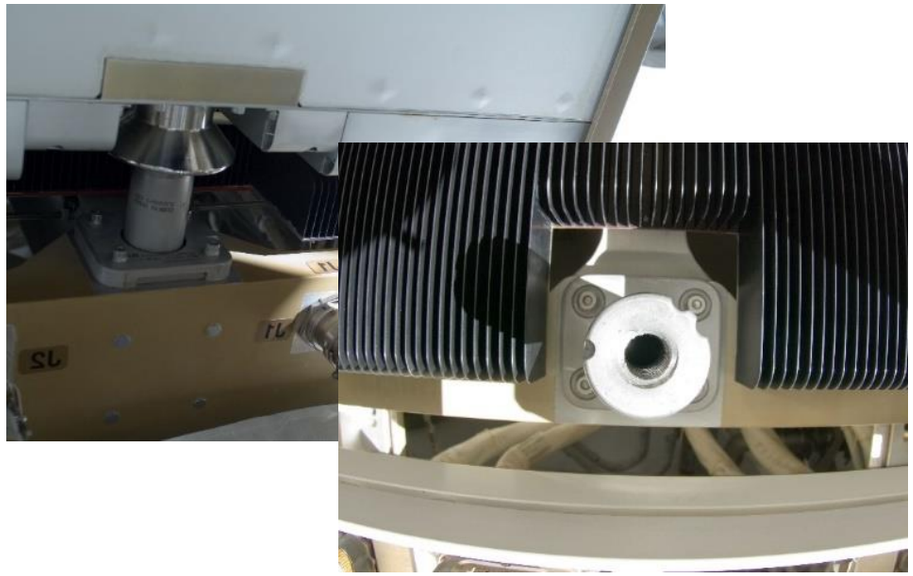


Two Bolts – How Hard Can It Be?

EVA Start



8 Hours Later

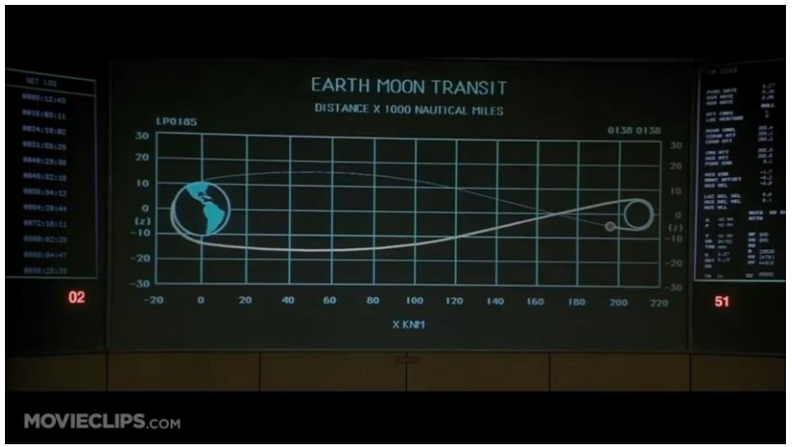


Six Days to Fix the Problem

- Choreographed turnaround is now an unplanned shutdown
  - Need to restore core ISS power channel as soon as possible
- Found and utilized technicians that originally installed MBSU
- Sought input and expertise from hardware experts as well as crewmembers who had installed similar (H-Bolt) ORUs on ISS previously
- Determined there were two problems
  - Foreign Object Debris had likely damaged the truss's bolt receptacle; possibly when originally installed but also during last spacewalk
  - Managing side loads on the jacking bolt was critically important
    - » Once the bolt receptacle was cleaned, dithering would be required!

Thread Cleaning
No Hardware Store Trips Allowed

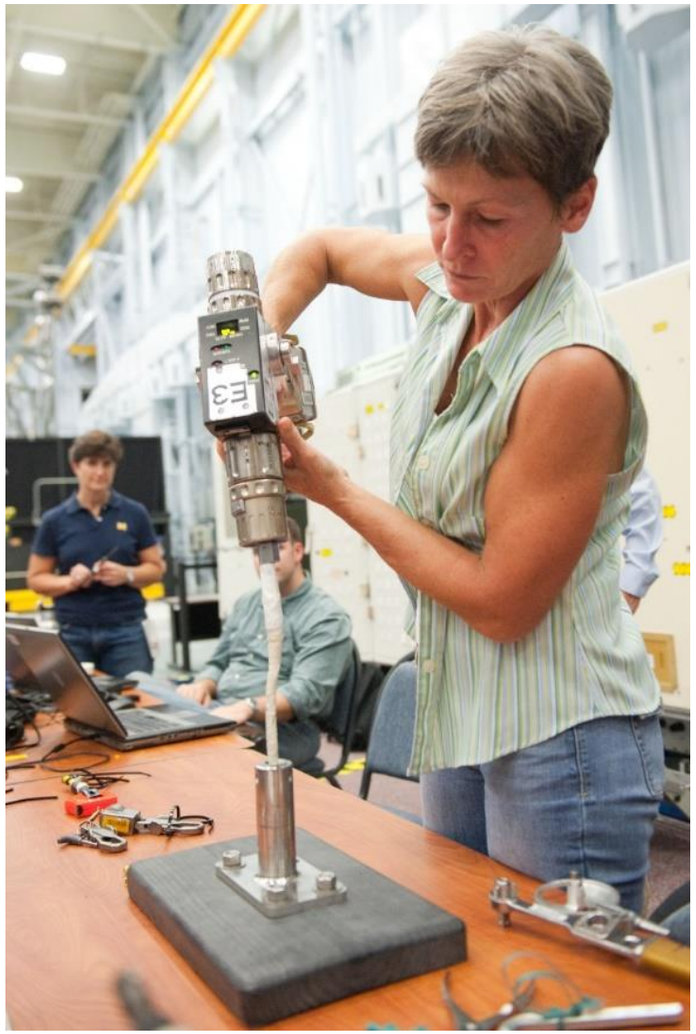
- **How do you clean threads without a tap and die set?**
  - **In space**
  - **In a spacesuit**
  - **With only the tools and parts you have on hand**
- **Simple – challenge your teams to do it and get out of their way**



MBSU Replacement Attempt #2

- **Step 1: Clean the threads**
  - **A: Take some 0 Gauge (large) wire, spread the individual conductors out, and create a ‘wire brush.’ Use Pistol Grip Tool (PGT, big cordless drill) to run wire brush in and out of receptacle**

Chimney Sweep



Ground version

On-orbit version

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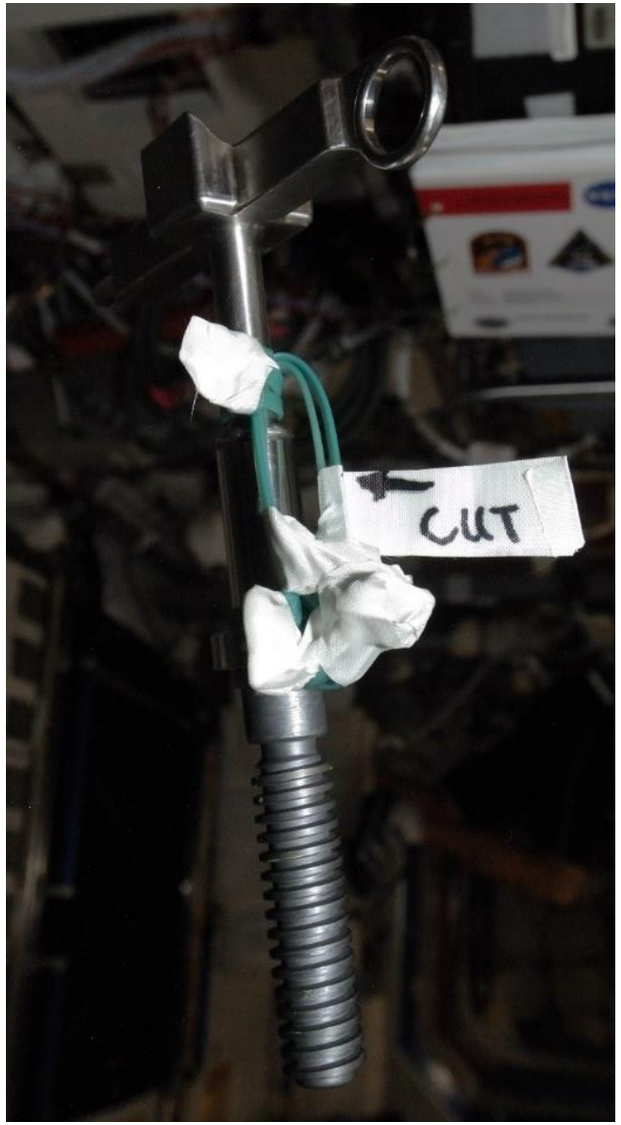
  - **B: Disassemble spare computer in the ISS to retrieve its jacking bolt (same size bolt). Use it to chase the threads.**

ACME Bolt



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  - **B: Disassemble spare computer in the ISS to retrieve its jacking bolt (same size bolt). Use it, attached to PGT, to chase the threads.**
  - **C: Use compressed air tool to blow debris out of threads**
  - **D: Use modified toothbrush covered in grease for lubricating solar array joint, attached to PGT, to lubricate threads**
    - » **Dry film lubricant was expected to have been removed on first spacewalk or by wire brush**

Toothbrush

MBSU Replacement Attempt #2

- Step 1: Clean the threads
  - A: Take some 0 Gauge (large) wire, spread the individual conductors out, and create a ‘wire brush.’ Use Pistol Grip Tool (PGT, big cordless drill) to run wire brush in and out of receptacle
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- **Step 2: Install by dithering all the way**

Dithering

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  - B: Disassemble spare computer in the ISS to retrieve its jacking bolt (same size bolt). Use it, attached to PGT, to chase the threads.
  - C: Use compressed air tool to blow debris out of threads
  - D: Use modified toothbrush covered in grease for lubricating solar array joint, attached to PGT, to lubricate threads
    - » Dry film lubricant was expected to have been removed on first spacewalk or by wire brush
- Step 2: Install by dithering all the way
- **Step 3: Complete any tasks possible that were supposed to be performed on previous spacewalk**

Success!

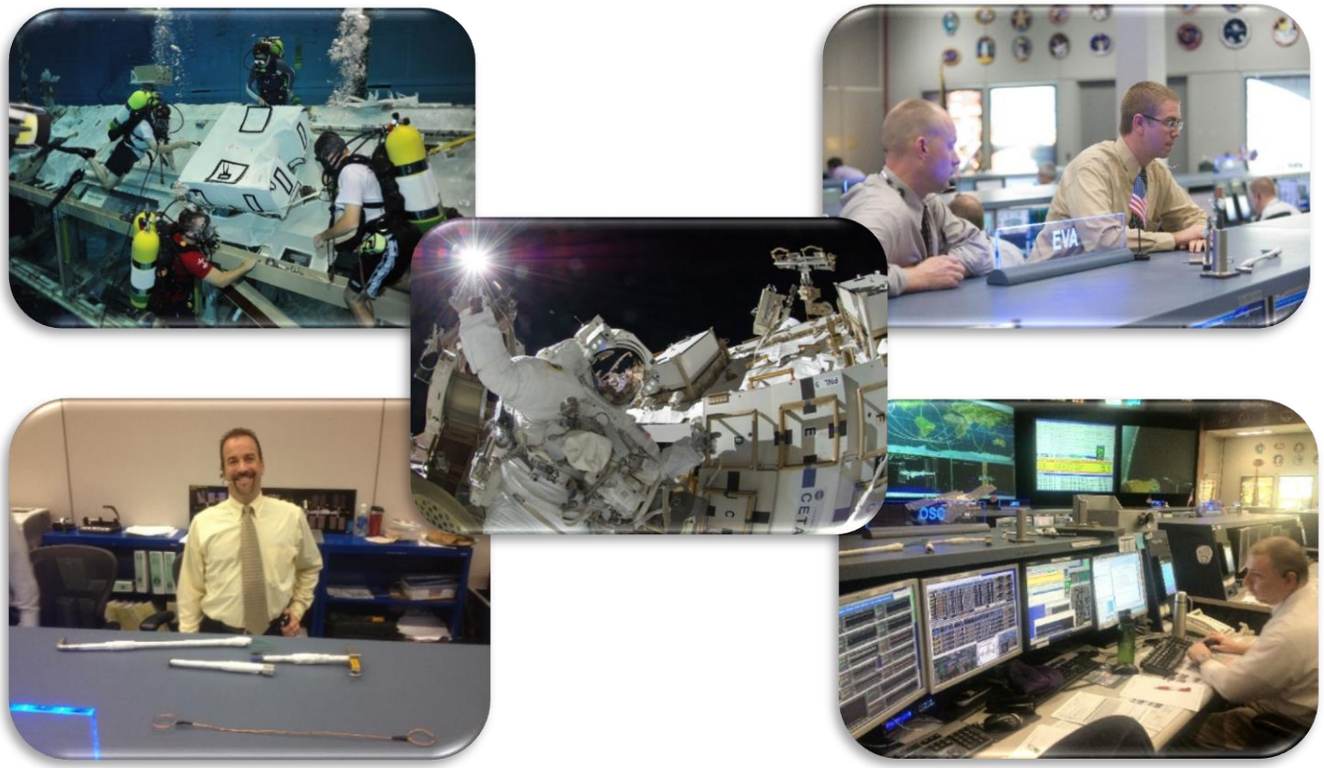
- **Successful due to having pre-established a culture of high performance and independent leadership**
  - **Could not have turned this around in 6 days if stovepipes, micromanagement, and management oversight bottlenecks had prevailed**

Q: Why didn't we have an accident?

A: We leveraged off our heritage of being a High Performing, High Reliability Organization

High Performing Organizations

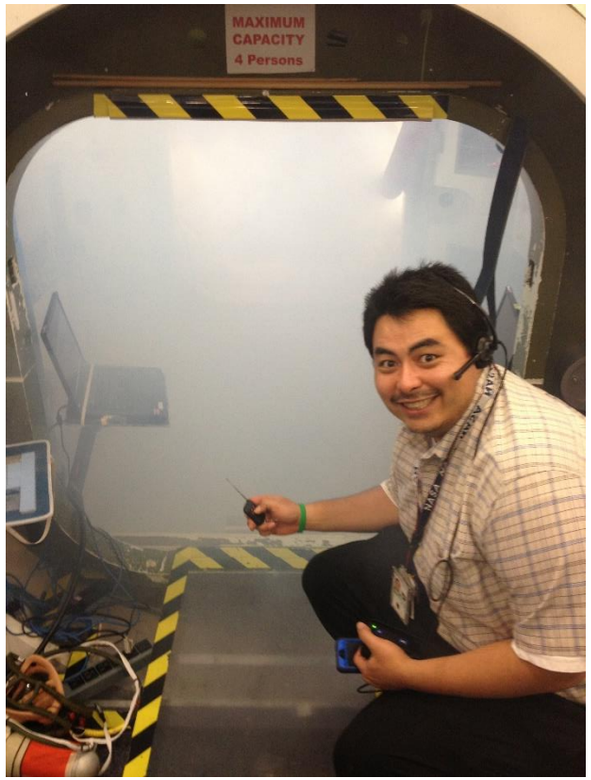
- **Leadership** – Leadership is aligned and effective deep within the organization
- **Design** – The structure is lean and reflects the organization's strategic focus
- **People** – The organization effectively translates business strategy into a powerful people strategy, attracting and retaining the most capable individuals
- **Change Management** – The organization can drive and sustain large-scale change and anticipate and adapt
- **Culture and Engagement** – The culture is shaped to achieve strategic goals. Employees pursue corporate objectives.



Source: Bhalla, Vikram; Caye, Jean-Michel; Dyer, Andrew; Dymond, Lisa; Morieux, Yves; Orlander, Paul (2011). "High-Performance Organizations, The Secrets of Their Success," Used with permission

High Reliability Organizations

- We were mindful that we had the right …
- Circumstances
  - Sensitivity to Operations
- Processes
  - Reluctance to Simplify Interpretations
- Culture
  - Preoccupation with Failure
  - Commitment to Resilience
  - Deference to Expertise



Source: Weick, Karl E.; Kathleen M. Sutcliffe (2001). Managing the Unexpected - Assuring High Performance in an Age of Complexity. San Francisco, CA, USA: Jossey-Bass. pp. 10–17. ISBN 0-7879-5627-9

Success Enablers

- **Leadership development**
  - Infuse in culture of management, engineering, operations, crews
  - Purposeful development from the very beginning
  - Empower leadership at the lowest possible levels
- **Collaboration across organization**
  - Not just within operations organizations but across management, engineering, customers, operations, crew
  - Collaboration is a success multiplier – as long as the team at the end of the spear (operations) can translate it into execution
- **Paradigm shifts**
  - Look for them, be open to them, welcome them – even when it's painful
- **Designing for operability, reliability, and maintainability increases mission adaptability and flexibility**

Links and Information

- **Social Media**
  - **Twitter**
    - **Ed: @Carbon_Flight**
    - **NASA: @NASA**
    - **Space Station: @Space_Station**
    - **Astronauts: @NASA_Astronauts**
  - **Snapchat**
    - **Ed: cflight78**
    - **NASA: NASA**
  - **Facebook: carbonfd@gmail.com**
  - **LinkedIn: *https://www.linkedin.com/in/edvancise***

- **Internet Links**
  - **Spot the Space Station from nearly anywhere on Earth: http://spotthestation.nasa.gov**
  - **More on the Space Station: http://www.nasa.gov/mission_pages/station/main/index.html**
  - **More on humans going beyond Earth: http://www.nasa.gov/topics/journeytomars/index.html**
  - **More on our solar system: http://www.nasa.gov/topics/solarsystem/index.html**

- **Video:**
  - **NASA Television: www.nasa.gov/multimedia/nasatv/index.html**
  - **NASA High Definition Earth Views from ISS: http://www.ustream.tv/channel/iss-hdev-payload**
  - **Live video (external or internal) from ISS: http://www.ustream.tv/channel/iss-hdev-payload**
  - **ISS Symphony: https://youtu.be/wgdbZhnFD5g**
  - **Riding the Boosters: https://youtu.be/2aCOyOvOw5c**
  - **Longer booster video: https://youtu.be/cLl7oqdm_B8**